

## A DRY MARS: LIMITED CHEMICAL WEATHERING OF SURFACE DEPOSITS BY LIQUID WATER

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**Overview:** Erosional features on Mars indicate that liquid water was once active at the surface. The mineralogical information available, however, suggests that chemical weathering of primary rocks and the formation of carbonates did not occur in abundance. Furthermore, recent TES data reveal the presence of relatively unweathered igneous rocks in the low albedo regions of the planet. Our work shows: (a) Hydrated minerals formed at the martian surface are not efficiently destroyed by ultraviolet radiation, even over geologic timescales, (b) the strong 3 micron absorption in martian soils typically attributed to hydrated phases can result from less than 0.5 weight percent adsorbed water on anhydrous grains, and (c) oxidation of meteoritic iron in the absence of liquid water, rather than aqueous alteration of ferrous minerals, can generate the ferric coloration of the martian surface. These pieces of data lead us to believe that chemical weathering of surface deposits by liquid water was not a significant process at the martian surface.

**Water on Mars?** Images of Mars reveal outflow channels, valley networks, and other geologic features that have been explained by the action of liquid water at the surface. Estimates of the quantity of water responsible for these features suggest a global inventory equivalent to a layer 400 meters thick at the surface of the planet [1]. Was this water stable as a liquid at the martian surface and available for chemical weathering of the surface rocks, or were these erosional episodes relatively short-lived and within a sub-freezing environment like at present?

*Absence of carbonates.* An apparent problem with an interpretation of martian history that involves widespread and sustained surface interactions with liquid water is that mineralogical evidence consistent with such climatic episodes remains weak. Attempts to identify carbonates, clays, and other hydrated minerals on the martian surface have not been greatly successful. Interactions between water and the thick carbon dioxide atmosphere (several bars) necessary to sustain its liquid form would have resulted in the precipitation of carbonates and the collapse of the atmosphere (assuming no re-supply) on timescales of  $\sim 10^7$  years [2]. The conversion from 1 bar of atmospheric CO<sub>2</sub> to carbonates would result in a layer equivalent to tens of meters over the entire planet. Yet, spectroscopic searches have not yielded any unambiguous detections of carbonate on Mars.

*Absence of clays.* Extensive aqueous weathering of the pyroxenes and feldspars believed to be on Mars would have resulted in the formation of clay minerals [3]. The cation-OH modes near 2.2 microns character-

istic of clay minerals are conspicuously absent from reflectance spectra suggesting that crystalline clays are not abundant on Mars [4].

*Recent TES data.* Furthermore, recent spectra from the MGS Thermal Emission Spectrometer indicate the presence of relatively unweathered pyroxenes in the low albedo regions of the planet [5]. In a water-rich environment, pristine pyroxene surfaces would rapidly be converted to weathering products such as clay minerals and hematite. Neither of these secondary phases are detected in conjunction with the pyroxenes. Based on terrestrial weathering rates [6], a 100 micron layer of weathering rind would develop in less than  $10^4$  years. Even this relatively short exposure to an aqueous weathering environment would likely mask the entire pyroxene signal for TES. This is further evidence suggesting that an environment that could maintain liquid water never existed at the martian surface.

**A Dry Mars?** If liquid water were once ubiquitous at the immediate surface, then, we argue, carbonates, clays, and/or hydrated mineral deposits should also be observable at the surface. Some mantling and redistribution would have occurred after formation, but we nonetheless consider it puzzling that none of these minerals has been positively identified. Here, we present three sets of laboratory results that support the alternative viewpoint that liquid water never had significant chemical interactions with the surface that we see on Mars today.

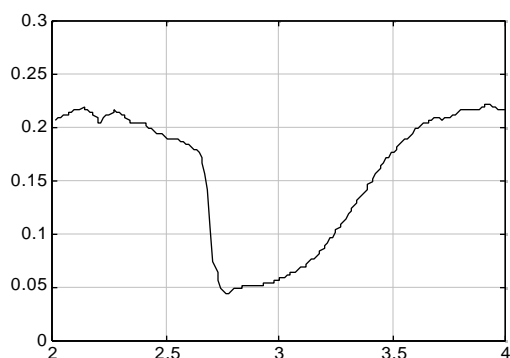
*No UV-dehydration.* First, we explore the possibility that ultraviolet radiation at the martian surface is capable of converting hydrated minerals to anhydrous phases, and that this process could explain the current lack of hydrated minerals that formed from ancient lacustrine processes. We pursued this idea by developing a laboratory experiment based on a mass spectrometer that measured the gas phases evolved from various mineral samples when exposed to an ultraviolet lamp. We were not able to detect an enhancement in the dehydroxylation of iron oxyhydroxides when exposed to the UV flux [7]. The sensitivity level of the experiment allowed us to set a minimum UV exposure time of  $10^8$  years for any UV-dehydration effect on Mars. A given mineral surface is unlikely to be exposed to UV for this length of time, and thus, we conclude that UV-induced dehydration of minerals is not an active process on Mars. Therefore, exposure to UV radiation at the martian surface cannot explain an absence of hydrated minerals.

*Strong absorption not necessarily bound water.* Second, the presence of a deep 3 micron absorption in

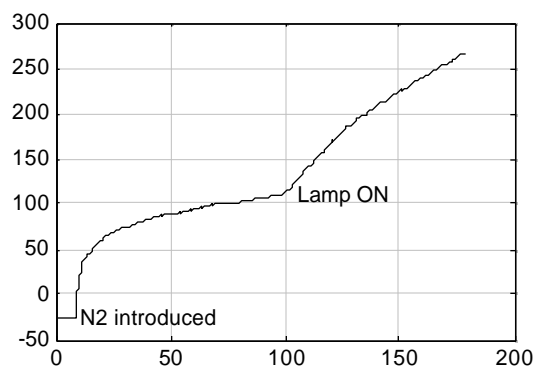
the surface reflectance spectra has been suggested as indicative of hydrated minerals at the surface. We have shown, however, that this strong absorption feature could be the result of less than 0.5 weight percent water adsorbed on anhydrous mineral surfaces (see figure 1) [8]. This quantity of water could simply be surface water molecules in equilibrium with the water vapor in the atmosphere and does not necessarily imply the presence of hydrated minerals.

*Ferric iron from iron meteorites.* Third, the abundance of ferric oxides is typically cited as strong evidence for chemical weathering of the surface. According to [9], ferrous iron dissolves in aqueous solutions, oxidizes to ferric iron, and results in precipitates of iron oxyhydroxide minerals. As discussed in the first set of laboratory experiments, above, hydrated phases rather than their oxide counterparts should be the minerals detected at the surface today if this scenario were valid. In addition, we have conducted experiments which show that metallic iron can be oxidized into the ferric phases believed to be on Mars (maghemite and hematite) under conditions similar to the current martian environment and in the absence of liquid water. We show that electron-beam deposited Fe films rapidly oxidize upon exposure to ultraviolet radiation (see figure 2). Furthermore, x-ray power diffraction spectra confirm that the resulting oxides are maghemite and hematite, consistent with spectral analyses of the soils and the results of the Viking and Pathfinder magnetic properties experiments (see figure 3). Thus, meteorites rich in metallic iron vaporized and re-condensed in the martian atmosphere could be the source of the ferric iron pigment and the small particle sizes of the dust without having had any interactions with liquid water.

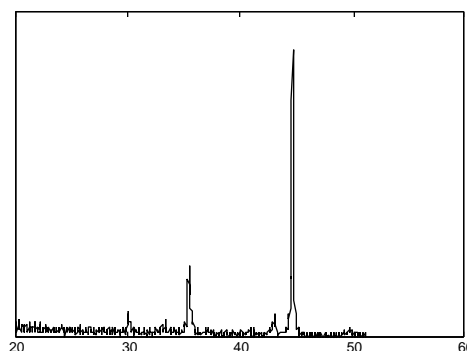
**Conclusion:** Mineralogical evidence for extensive interactions between liquid water and surface materials on Mars is absent. Our laboratory data and recent results from TES are consistent with the interpretation that widespread chemical weathering by liquid water did not occur at the martian surface.



**Figure 1:** Reflectance versus wavelength in micrometers showing 3 micron absorption for less than 0.5 weight percent water on dune sands.



**Figure 2:** Fe thin film resistance measured in millivolts across a bridge versus time in hours. Nitrogen gas impurities introduced and oxidized film at  $T=8$  hours. UV lamp further increases rate of oxidation at  $T=100$  hours.



**Figure 3:** X-ray powder diffraction analysis showing the initial metallic iron (peak at  $2\text{-theta} = 44.7$ ) and the oxide maghemite (peaks at  $2\text{-theta} = 30.3, 35.7,$  and  $43.4$ ) after exposure to UV radiation.

**References:** [1] Carr, M. H (1986) *Icarus*, 56, 187-216. [2] Pollack, J. B. et al. (1987), *Icarus*, 71, 203-224. [3] Gooding, J. L. (1978), *Icarus*, 33, 483-513. [4] Banin, A. (1996) *Adv. Space Res.*, 18, 233-240. [5] Christensen, P. R. et al. (1998), *Science*, 279, 1692-1698. [6] Brantley, S. L. and Y. Chen (1995) in *Reviews in Mineralogy* (v. 31). [7] Yen, A. S. et al., *JGR (in revision)*, [8] Yen, A. S. et al. (1998), *JGR*, 103, 11125-11133. [9] Burns, R. G. (1993), *Geochim. Cosmochim. Acta*, 57, 4551-4554.